

Simple Tools to Estimate Impacts of Development on Water Quantity, Water Quality, and Riparian Processes

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Abstract

Alternative future development scenarios for the Chico Creek watershed were evaluated in terms of potential impacts on natural resources. This paper presents results for water quantity, water quality, and riparian structure, and represents one of a series of analyses. Under current regulations, population and domestic water use could quadruple under possible future development, while runoff from impervious surfaces, fecal coliform levels, and total suspended solids concentrations could increase substantially. However, conservation-oriented development could minimize changes in impervious surface runoff and water quality, although doubling the population from current conditions may double the domestic water use. Alternatively, a moderate development scenario could absorb the population increase possible under current zoning. Thus, the moderate alternative future scenario would still require four times the current water use but with relatively small increases in impervious surface runoff and changes in water quality. Riparian forest structure, based on large woody debris recruitment potential, follows patterns of urban development. Fewer areas of high recruitment potential and more areas of low or no recruitment potential surround the more developed areas near the mouth of Chico Creek. These metrics represent a small subset of possible analyses but provide one part of a framework for analyzing relative potential impacts of alternative future development scenarios on resources in the Chico Creek watershed.

Introduction

The Alternative Futures approach provides a means for citizens and decision-makers to evaluate future land use within a natural resource context (U.S. EPA 2002). Previous analyses have been conducted in the Willamette River watershed, OR (Hulse et al. 2002); the San Pedro River watershed spanning the border between Arizona and Sonora, Mexico (Steinetz, et al. 2003); Camp Pendleton, CA (Steinetz et al. 1997); Monroe County, PA (Steinetz et al. 1995); and Blackberry Creek, Illinois (Illinois DNR 2002). Each project has developed different tools and has involved various combinations of academic institutions, local governments, state governments, international governments, interest groups, and citizens. Yet all efforts include common elements: (1) evaluate current conditions; (2) define alternative visions of the future; (3) develop appropriate tools and analyses; and (4) evaluate the alternative future scenarios.

Kitsap County initiated the Chico Creek Alternative Futures study in 2001 in cooperation with the Puget Sound Action Team and the U.S. Environmental Protection Agency. The project purpose is to understand how the Chico Creek watershed might develop and what the effect of development could be on natural resources.

Five groups of participants played key roles, which define the elements of the overall project:

- Chico Advisory Team—The CAT included Kitsap County staff and representatives of other organizations involved with natural resource management in the Kitsap area. The group was responsible for overall project direction and for developing the current assessment of the watershed.
- Education Working Group—The EWG developed components of a public education program for the residents of the Chico watershed and the general public. The EWG recognized the need to reach a common level of understanding of ecosystems, hydrology, and land surface processes to enable effective public participation in crafting ideas for future development.
- Public Involvement Working Group—The PIWG implemented the public education plan in a series of educational presentations and activities called the “Watershed Academy.” Academy participants learned fundamental planning and watershed process concepts.
- Technical Working Group—The TWG identified metrics that describe potential impacts of current and future development on watershed processes and developed the tools necessary to quantify those metrics. TWG participants represented county, regional, state, and federal governments, together with tribal and academic organizations. They developed one future scenario and applied the tools to each alternative future scenario.
- Watershed Advisory Committee—The WAC, composed of citizens of the Chico watershed and interested stakeholders who completed the Watershed Academy, discussed a variety of potential development patterns. Through a collaborative process, the WAC identified two¹ alternative future scenarios for the TWG to evaluate.

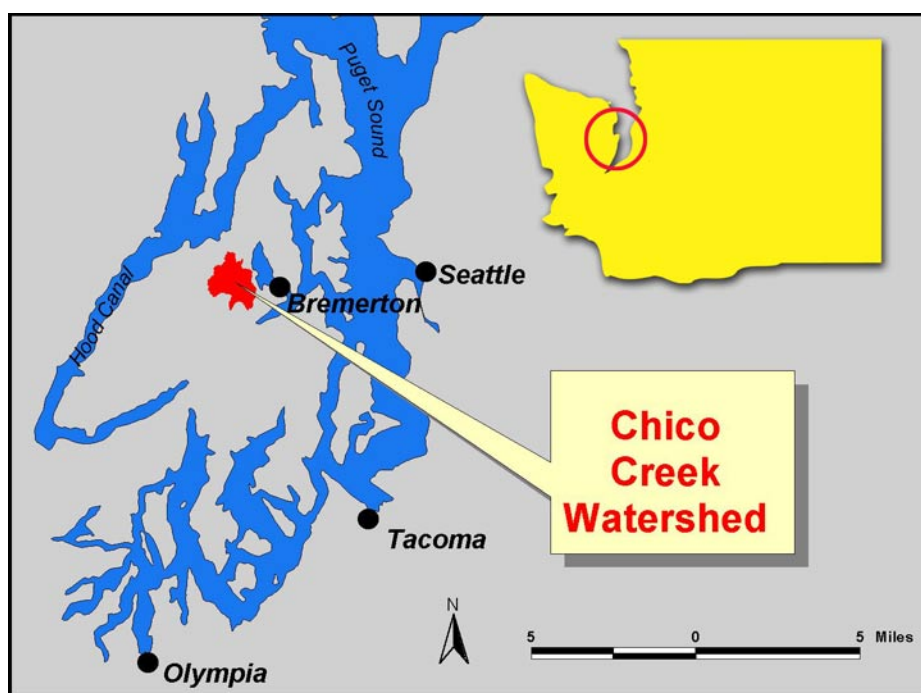


Figure 1. Location of the Chico Creek watershed.

In total, three alternative future conditions were analyzed. The TWG defined the *Planned Trend* scenario, based on interpretations of current zoning and regulations. The WAC created the *Conservation* scenario to minimize impacts of development and to explore potential protection and restoration options. The WAC then crafted the *Moderate* scenario to balance development and natural resource protection by incorporating specific low-impact development approaches. Nelson (2003a) details the characteristics of each scenario.

The TWG developed an extensive list of over 100 potential metrics. TWG members represented a wide array of technical expertise, yet not all metrics could be evaluated with the information available. The final analyses include quantitative and semi-quantitative assessments in the areas of hydrology, water quality, terrestrial wildlife habitat, geomorphology, and aquatic species. The complexity of tools varied as a function of time and resource constraints.

Description of the Chico Creek Watershed

Kitsap County selected the Chico Creek watershed due in part to its current low level of development, large salmon runs, and potential development pressure. The Chico Creek watershed occupies 16.3 mi² (42 km²), spanning the area from the Green and Gold Mountains (1,500 ft MSL, or 460 m) to Dyes Inlet and central Puget Sound. The watershed is located west of Bremerton on the Kitsap Peninsula (Figure 1). Currently most of the watershed is forested and is actively managed for timber resources. Residential and commercial development occur around two large lakes, along lower Chico Creek, and adjacent to major roads (Figure 2).

Annual precipitation varied from 45 in/yr (110 cm/yr) in the lower elevations to 65 in/yr (170 cm/yr) at the headwaters during WY2001-2002 (M. Morgan, Kitsap Public Utilities District [PUD], unpublished data). Stream discharge near the outlet averages 26 cfs (0.7 cms) annually, based on ten years of data (Kitsap PUD, unpublished data), with summer low flows on the order of 2 cfs (0.06 cms) and winter flows as high as 500 cfs (14 cms).

Channels are primarily riffle/pool systems forced by the presence of natural woody debris (Segura-Sossa et al. 2003). Some channel margins in the lower watershed are entirely constrained by bank armoring. The watershed includes benthic communities that are among the healthiest, and also among the most disturbed, on the Kitsap Peninsula, based on the benthic index of biological integrity (V. Koehler, Kitsap County Department of Community Development, personal communication). Kitsap Lake is very shallow with a surface area of 250 ac (97 ha). Wildcat Lake has a smaller surface area (120 ac, 46 ha) but has a maximum depth of 33 ft (10 m). In addition, a large wetland complex, located northeast of Wildcat Lake, produces surface flow primarily in the winter.

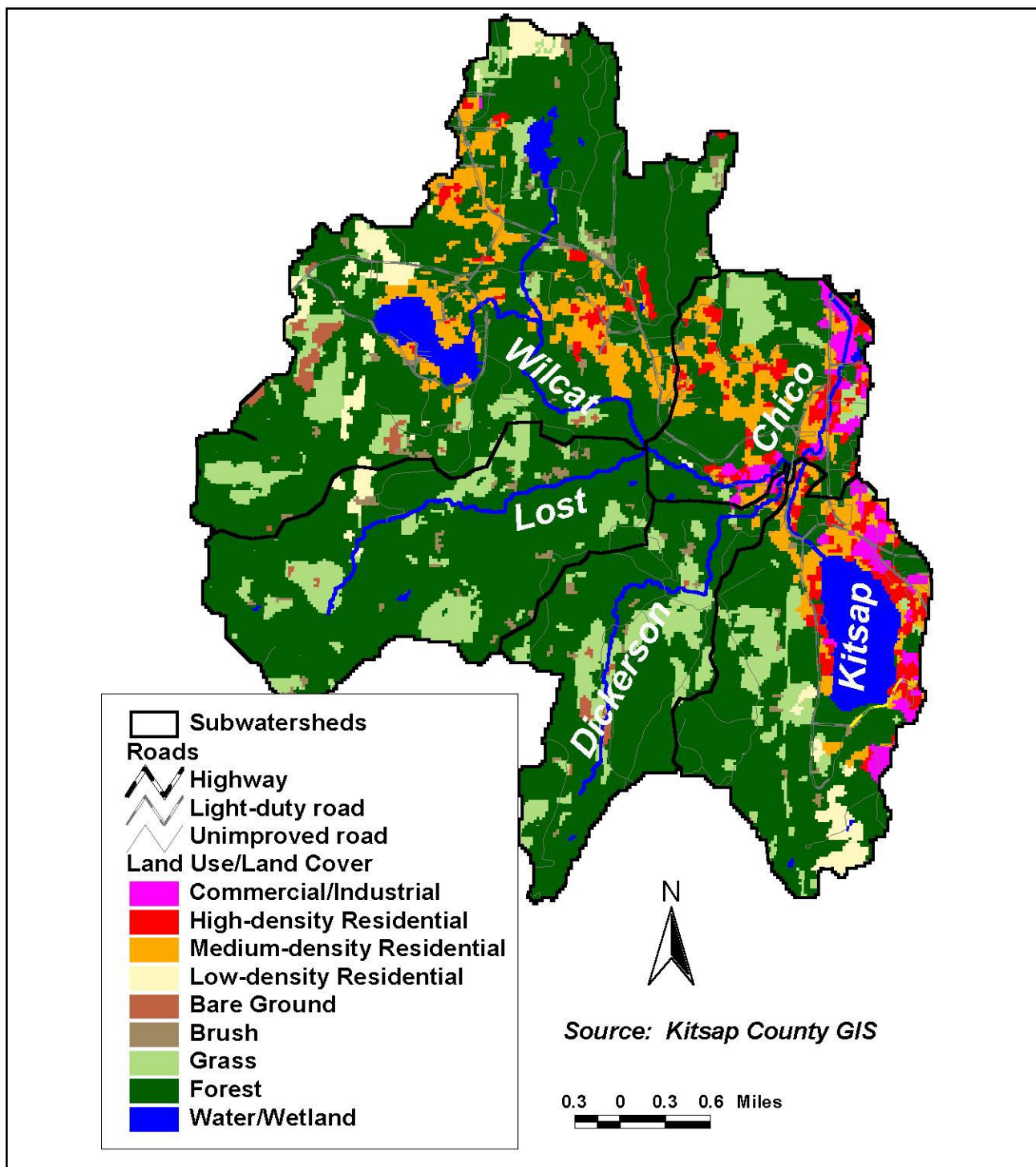


Figure 2. Chico Creek watershed land use/land cover (1999 data)

Conifers dominate upland vegetation, with western hemlock and Douglas fir the common species. Riparian areas contain conifer, hardwood, and mixed stands of western hemlock, Douglas fir, red cedar, red alder, and big leaf maple (Roberts, unpublished data) dominating.

Historically, wildlife species included black bear, bobcat, deer, and other large mammals (Paschall, 1916). Common species and species of concern modeled by Linders et al. (2003) include Douglas squirrel, blue grouse, bobcat, pileated woodpecker, great blue heron, red-legged frog, western toad, willow flycatcher, and downy woodpecker.

Chico Creek has the largest chum salmon run in the Kitsap Peninsula. Adult escapements average 25,000 fish (T. Ostrom, Suquamish Tribe, unpublished data). In 2001, over 40,000 chum spawned within monitored reaches of the Chico watershed. Historical runs have exceeded 100,000.

Purpose

This paper summarizes the approach to and results of evaluating potential impacts of alternative future development on water use, runoff from impervious lands, water quality, and riparian processes. Coincident analyses of terrestrial habitat (Linders et al. 2003), geomorphology (Segura-Sossa et al. 2003), aquatic species (Nelson 2003b), as well as a project overview (Nelson 2003a) provide a broad description of the effects of alternative future development scenarios on the natural resources of the Chico Creek watershed.

Methods

Several simple tools were developed and applied to specific metrics that describe potential environmental conditions. Existing data provide the analytical basis for the Alternative Futures scenarios.

Water Use

Most Chico Creek watershed residents derive residential water from private wells. Water use was estimated from zoning densities and current per capita water consumption rates. To estimate current and potential future population, Kitsap County GIS staff developed alternative future land use datalayers (Nelson 2003a), with areas of development and a range of housing unit densities specified. The midpoint of the range was used to estimate potential population increases, based on County-wide densities of 2.5 people/unit. Kitsap PUD provides drinking water to areas outside the Chico Creek watershed. However, water use within the service area is believed to be representative of use within the Chico watershed. Kitsap PUD and its consultants estimated current per capita water consumption at 72 gal/person/day (270/L/person/day) (B. Hahn, Kitsap PUD, personal communication). Water consumption declined by about 15% between 1989 and 2000, but the 2000 consumption rates were held constant in the future scenarios. The method does not include water conservation programs beyond those currently in practice or other behavioral changes that would alter domestic consumption.

Runoff from Impervious Lands

Annual runoff was estimated from the volume of precipitation that falls on pervious and impervious lands multiplied by a runoff coefficient². Daily discharge and precipitation data from Kitsap PUD for water year 2001 (M. Morgan, Kitsap PUD, personal communication) were used to check the reasonableness of the approach. Precipitation from the Green and Gold Mountains station was applied to the higher-elevation sub-watersheds (Lost, Dickerson, and upper Wildcat), while precipitation from the nearby Bremerton Airport station was used for the lowland sub-watersheds. Hydrologically impervious lands include pavement and buildings, as well as the lake surfaces, wetlands, and bare ground (forestry roads). Runoff coefficients of 0.9 for impervious lands and 0.2 for pervious lands with the current proportion of impervious surface cover in the watershed (7.2% pavement/buildings and 23.0% total) yield an annual runoff of 26 cfs, close to the measured value of 27 cfs. The method, similar to that of Schueler (1987), provides a simple approach to estimating total annual runoff. No historical low-impervious cover discharge or precipitation data are available to evaluate changes over time. The method does not account for infiltration of runoff from new development.

Water Quality

The Kitsap County Health District (KCHD) monitors many sites throughout the Kitsap Peninsula, including four stations along the main stem of Chico Creek (KCHD 2002). The stations provide a range of percent urban lands upstream, from 7.2% at the most upstream station to 12.5% at the most downstream station. Urban lands were determined from the 1999 land use/land cover classification (Kitsap County GIS data), and include both impervious and pervious lands associated with the high-density residential, medium-density residential, and commercial/industrial land uses.

KCHD data from 1996 through 2001 were used to calculate the geometric mean and maximum fecal coliform concentrations, average and maximum total suspended solids (TSS) concentrations, and minimum dissolved oxygen (DO) concentrations for each Chico station. Percent urban lands explained little variability of maximum fecal coliform or minimum dissolved oxygen levels, and these parameters were dropped from the analysis. However, linear regression explained much of the variability of the geometric mean fecal coliform, average TSS, and maximum TSS concentrations, and these relationships were used to link future percent urban lands to these water quality parameters.

Current and future geometric mean fecal coliform concentrations are compared with the State of Washington water quality standards (WAC 173-201A-030(2)(c)(i)) as a point of reference. Washington uses a two-part standard, including both the geometric mean and the 90th percentile concentration. However, only the geometric mean concentrations were compared with the criterion of 100 organisms/100 mL.

The land use definitions developed for the alternative future scenarios do not include the same classifications used to estimate percent urban lands. Therefore, percent urban lands was assumed to increase proportionately with the increase in impervious area. The method assumes no additional management of fecal coliform or TSS sources and no aging of wastewater infrastructure, which could change relationships between land cover and pollutant levels.

Large Woody Debris (LWD) Recruitment Potential

Near-term LWD recruitment potential was developed using orthophotos (Kitsap County GIS), LiDAR data (Puget Sound LiDAR Consortium), and field observations (Roberts, unpublished data) based on categories developed for forest practices (WFPB 1997). To encompass areas with the potential to influence channel processes, a 500-foot (150-m) buffer was established around the centerlines of primary tributaries in the Chico Creek watershed using ArcView®. Next, polygons were delineated to distinguish unique combinations of forest composition (>70% conifers, >70% hardwood, or mixed forest); density (*sparse* for >33% bare ground exposed, *dense* for <33% exposed); and size, where height was used as a proxy for diameter at breast height (DBH)³. Table 1 summarizes the recruitment potential categories. Data summaries are based on a buffer of approximately 100 ft (30 m) to either side of the stream channel, in accordance with WFPB (1997).

Table 1. Near-term large woody debris recruitment potential categories as a function of riparian vegetation composition, density, and size, based on WFPB (1997)

Conifers	Height (ft)	Height (m)	Dense	Sparse
Large	>150 ft	>46 m	High	Medium
Medium	50 to 150 ft	15 to 46 m	High	Medium
Small	<50 ft	<15 m	Low	Low
Mixed			Dense	Sparse
Large	>150 ft	>46 m	High	Medium
Medium	50 to 150 ft	15 to 46 m	High	Medium
Small	<50 ft	<15 m	Low	Low
Hardwoods			Dense	Sparse
Large	>150 ft	>46 m	Medium	Low
Medium	50 to 150 ft	15 to 46 m	Medium	Low
Small	<50 ft	<15 m	Low	Low

Vegetation plot data (Roberts, unpublished) indicate that very few areas have an average DBH >20 in (>51 cm), and the 150-ft (46-m) threshold was selected to reflect that. The 50-ft (15-m) threshold was selected based on field observations to discriminate between immature and established trees.

Results

Water Use

Figure 3 summarizes current and potential future water use associated with the Conservation, Moderate, and Planned Trend scenarios. In proportion to potential population increases, water use could double in the Conservation scenario, while water use could quadruple in both the Moderate and Planned Trend scenarios.

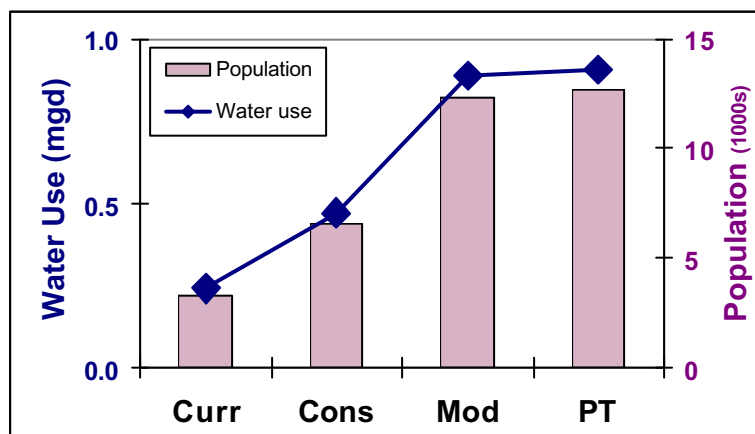


Figure 3. Current and potential future domestic water use and population (consumption data source: Kitsap PUD).

Runoff from Impervious Lands

The current level of traditional impervious (pavement and buildings) cover is 7.2% in the Chico Creek watershed. The Conservation scenario could increase impervious cover to 8.9%, which would increase the volume of runoff from impervious surfaces by 24% over current levels, as shown in Figure 4. The Moderate scenario could increase impervious cover to 9.2% for a 29% increase in the amount of runoff from impervious surfaces. Annual runoff likely would not change measurably under the potential land surface changes under either the Conservation or the Moderate scenario. The Planned Trend scenario could increase annual runoff somewhat, but runoff from impervious lands could increase by 45% compared with current levels.

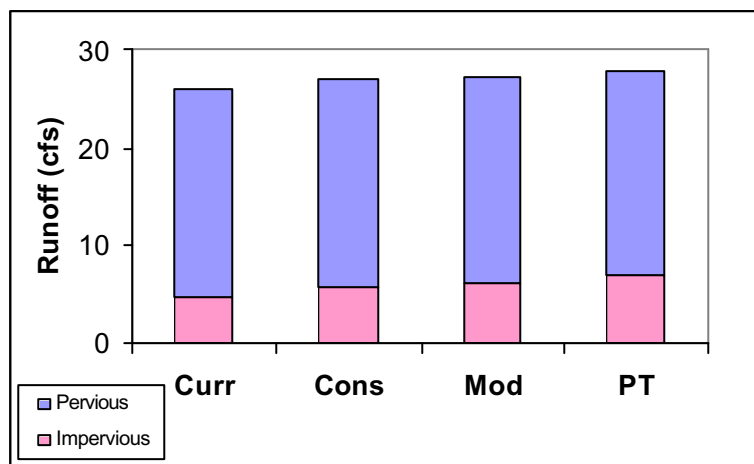


Figure 4. Potential changes in annual runoff from pervious and impervious (pavement and buildings) surfaces in the Chico Creek watershed.

Water Quality

The current geometric mean concentration of fecal coliform bacteria is low and meets the criterion in the water quality standards. The increases in impervious surfaces associated with the Conservation, Moderate, and Planned Trend scenarios could increase bacteria concentrations, but levels should remain below the water quality standard based on the linear model (Figure 5).

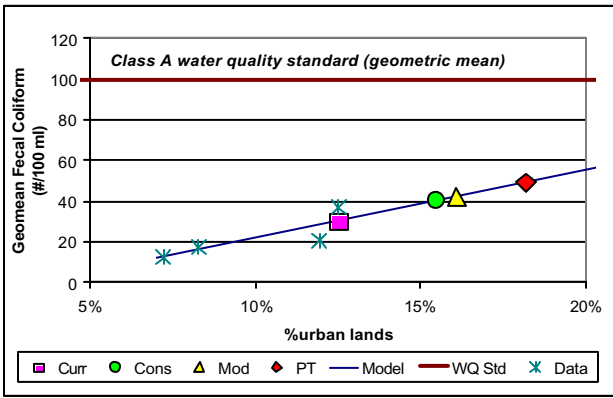


Figure 5. Geometric mean fecal coliform concentration as a function of percent urban lands for current and potential future conditions ($R^2 = 0.69$) (data source: KCHD)

Current average TSS concentrations are relatively high in the watershed, due to the high concentrations associated with wet-weather events. The Conservation and Moderate scenarios could increase levels significantly, and the Planned Trend scenario could double the average TSS levels, based on current patterns used to develop the linear model in Figure 6. Similarly, maximum TSS levels could increase significantly for the Conservation and Moderate scenarios and could double for the Planned Trend scenario (Figure 7).

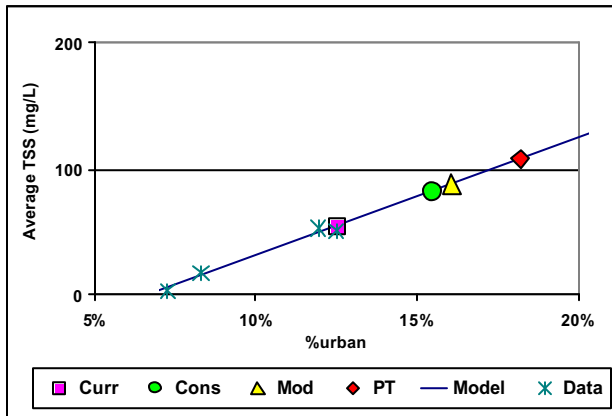


Figure 6. Average TSS concentration as a function of percent urban lands for current and potential alternative future scenarios ($R^2=0.98$) (data source: KCHD)

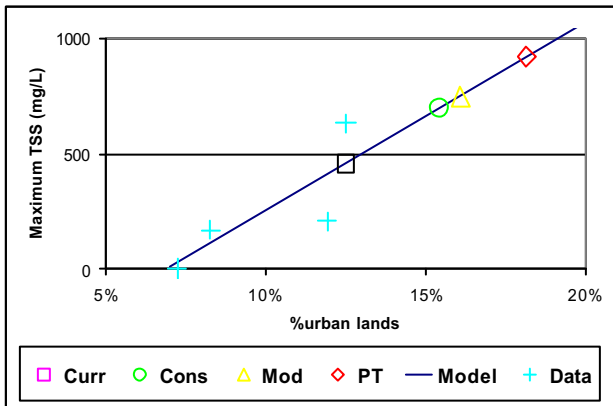


Figure 7. Maximum TSS concentrations as a function of percent urban lands for current and potential alternative future scenarios ($R^2 = 0.64$) (data source: KCHD)

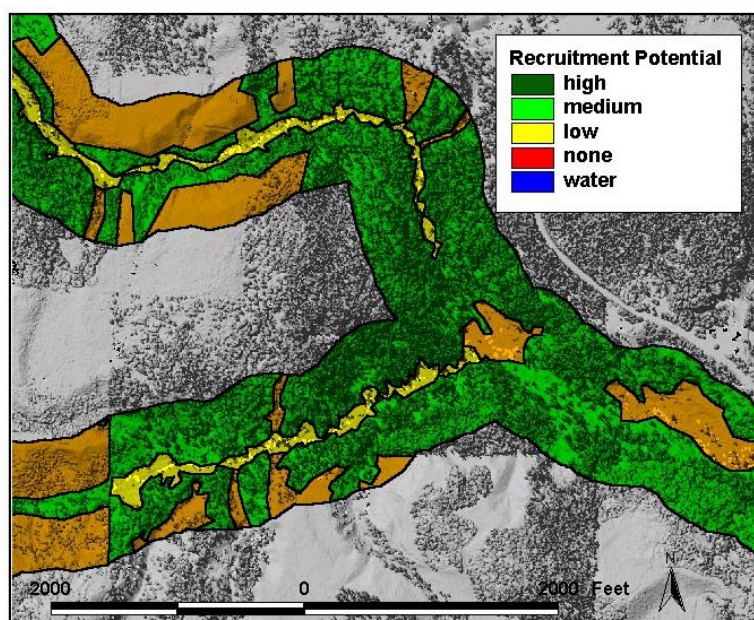


Figure 8. Example of LWD recruitment potential in area of mature vegetation (confluence of Lost and Wildcat creeks) (LiDAR data source: PSLC).

LWD Recruitment Potential

LWD recruitment potential varies by location in the watershed. At the confluence of Lost and Wildcat creeks, lands have been minimally disturbed and are protected by a conservation easement (Figure 8). Tall (>200 ft, or >60 m), dense conifer stands, representing a high recruitment potential, dominate the floodplain, terraces and lower hillslopes, whereas hardwoods of medium height, with a medium recruitment potential, occupy the channel margins. Below the confluence, two clearings are visible where most of the riparian trees have been removed and the area converted to residential use; these areas represent low recruitment potential. Upland areas above the confluence are subject to timber harvest, and these represent low recruitment potential as well.

Much of the riparian area in the lower watershed has been disturbed (Figure 9), and few areas of high recruitment potential remain. The riparian forest shifts to more of a hardwood-dominated system with medium recruitment potential. This region also has abundant areas of pavement and buildings, which are presumed to have no recruitment potential.

The overall pattern is illustrated in Figure 10. Within a 100-ft (30-m) buffer of the stream channel, over 60% of the forest has a high recruitment potential (Figure 11). In the lower watershed, over a third of the buffer has low or no near-term LWD recruitment potential. Paralleling this distinction, the geomorphology study (Segura-Sossa et al. 2003) also noted a distinct change in channel characteristics in the upper and lower watershed.

Summary and Conclusions

These simple analyses for potential changes in water use, hydrology, and water quality, as well as the current riparian condition, constitute one part of a larger analysis that includes terrestrial wildlife habitat, geomorphology, and aquatic species impacts in the Chico Creek watershed under alternative future development scenarios. They are intended not as a detailed assessment, but as a general picture of how the watershed might look in the future. The purpose was to place future development in a natural resource context to allow citizens to explore alternative planning strategies.

As discussed in Nelson (2003a), the WAC decided that the current zoning and regulations embodied by the Planned Trend scenario represent a worst-case scenario for the Chico Creek watershed. Therefore, the group produced the Moderate scenario to absorb a similar population but with less of an overall natural resources impact. The Conservation scenario represents a step toward restoration, and several of the ideas discussed as part of the Conservation scenario were included in the Moderate scenario.

The metrics described above illustrate the relative differences among scenarios. The Conservation scenario would double the domestic water needs as the population doubles but may not change impervious runoff or water quality significantly

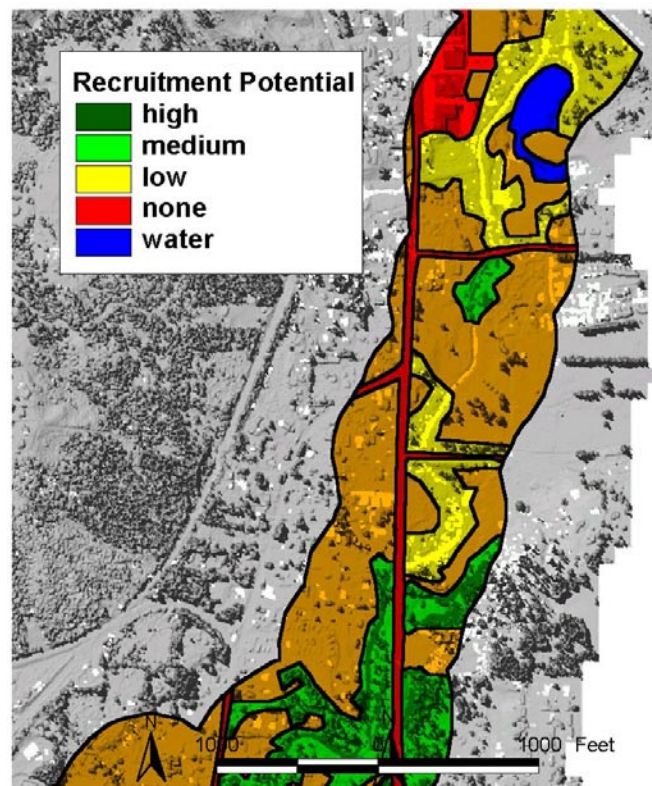


Figure 9. Large woody debris recruitment potential in disturbed vegetation (lower Chico watershed) (LiDAR data source: PSLC)

compared to current conditions. The Moderate scenario absorbs twice the population of the Conservation scenario, but minimizes increases in impervious areas compared with current and potential Conservation alternative future scenario levels, which results in similar impacts. By comparison, the Planned Trend scenario could increase water use, hydrology, and water quality impacts relative to both current conditions and the Conservation or Moderate scenarios.

The analyses do not presume changes in behavior or management strategies in the future, since these were believed to be more uncertain than changes in population or impervious area. For example, water conservation programs could significantly reduce water demand in the future. Yet, these reductions could not be quantified based on existing information appropriate to this level of analysis, and current consumption levels were applied to future populations. Similarly, adoption of current stormwater practices during redevelopment of sites or new strategies that emphasize maintaining native vegetation and soil during construction could further reduce the hydrologic impact of development.

These simple tools provide a framework for analyzing relative potential impacts from alternative future development scenarios on resources in the Chico Creek watershed. The metrics represent a small subset of possible analyses that describe potential changes in natural resources, and are not intended as a complete assessment. However, the metrics relate changes in land cover to potential changes in relevant parameters, such as water use. Thus, land surface changes are represented as potential natural resource impacts.

Acknowledgements

David Nash (Kitsap County GIS) translated alternative future management strategies to specific GIS coverages and attributes, which underpinned the hydrologic and water quality analysis. This effort benefited from previous hydrologic data collection efforts of the Kitsap PUD Hydrologic Services division, and the water use estimates by Kitsap PUD and its consultant. The Kitsap County Health District provided fecal coliform, TSS, and dissolved oxygen data, which were fundamental to the evaluation of potential water quality impacts, and reviewed findings of the regression analysis. The Puget Sound LiDAR Consortium provided LiDAR data of the Chico Creek watershed. David Nash processed the LiDAR data to a usable format for the Chico analysis. Funding was provided by a grant from the Puget Sound Action Team and U.S. EPA Region X.

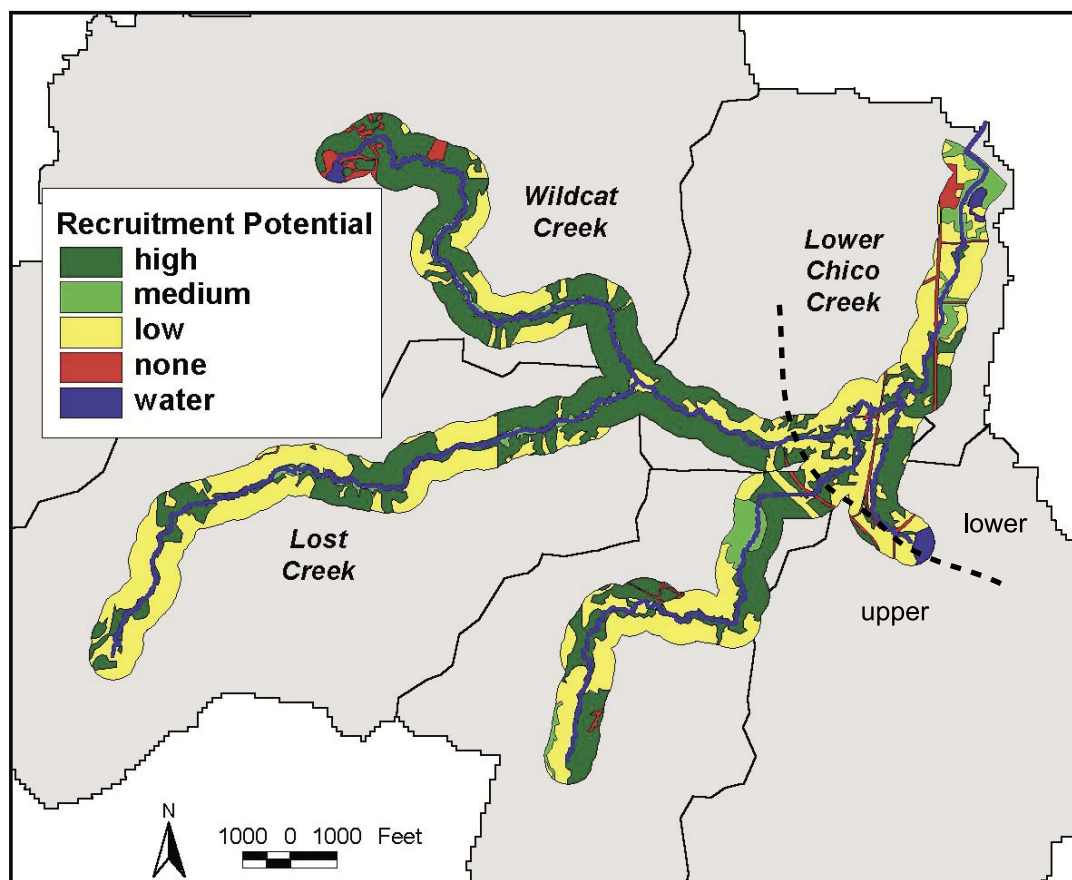


Figure 10. Large woody debris recruitment potential within 500-ft (150-m) buffer of stream centerline.

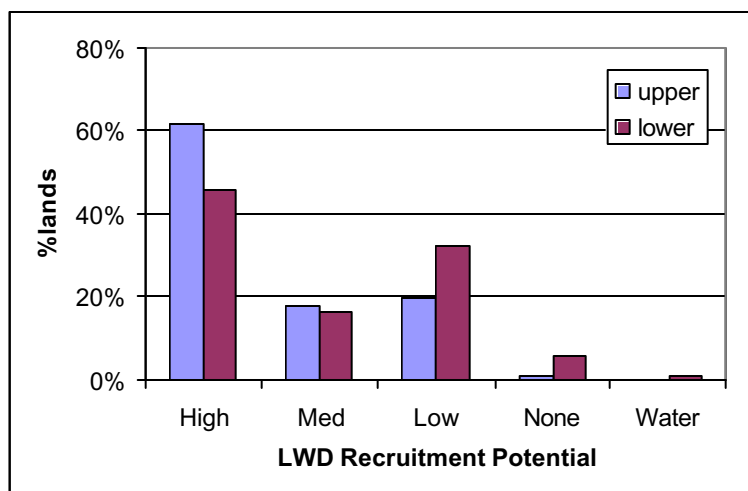


Figure 11. Recruitment potential within a 100-foot (30-m) buffer of the channel in the upper and lower watershed.

Notes:

¹ The WAC developed a third maximum development scenario but did not want it analyzed because it was implausible.

² Initially, the effort intended to use a hydrologic model, HSPF, to simulate the current and future hydrology of the Chico Creek watershed. However, the relatively low increases in impervious surface produced only marginal changes in modeled runoff characteristics. Recent gaged discharge data include missing data. Also, a precipitation gage was installed only recently in the headwaters, but the short period of overlap indicated significant orographic effects such that the lowland site did not represent the headwaters in storm frequency or magnitude. Land-cover data layers associated with each alternative were not developed until late in the project. Therefore, rather than construct a precipitation record for the headwaters, fill in gaps in the discharge record, calibrate to both of these records, then apply the model anew to a series of future landscapes, the numerical modeling effort was abandoned in favor of a simplified runoff coefficient approach. The approach is reasonable only for the stated project purpose: to provide a relative measure of the potential impacts of future development. However, future efforts should consider a hydrologic model at an appropriate scale.

³ Large trees are defined as DBH >20 in (>51 cm), medium trees as DBH of 12 to 20 in (30 to 51 cm), and small trees as DBH <12 in (<30 cm).

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